Marasco, P. L. (2001). The visibility of night vision imaging system compatible displays. *Proceedings of the 39th Annual Symposium SAFE Association*, http://www.safeassociation.com

THE VISIBILITY OF NIGHT VISION IMAGING SYSTEM COMPATIBLE DISPLAYS

Peter L. Marasco, Ph.D.

Research Physicist
Air Force Research Laboratory
Human Effectiveness Directorate
AFRL/HECV
2255 H St., Rm. 300
Wright-Patterson AFB, OH 45433

ABSTRACT

In an effort to incorporate color displays into night vision imaging system (NVIS) compatible cockpits, the F-16 System Program Office, through Lockheed Martin Tactical Aircraft Systems, requested Honeywell's Aerospace Electronic Systems division to design and construct a prototype color multifunction display. Observers indicated during preliminary operational testing that this display, when configured in NVIS mode, did not present video with the desired level of detail and was too dim to easily read under certain conditions. Testing showed that the Honeywell display met the existing MIL-L-85762A NVIS B radiance compatibility criteria required by contract. However, during a demonstration of the display, F-16 pilots with night vision goggle experience insisted that the display's visibility was marginal, reiterating their concerns on display legibility. This paper discusses the testing of the color multifunction display and potential factors that could be limiting the visibility of the display, in particular, the size of the characters displayed and the luminance levels specified in MIL-L-85762A.

INTRODUCTION

Full color displays are desirable in the cockpit because color-coding adds information in an easily understandable way. However, night vision imaging system (NVIS) compatible cockpits traditionally avoid employing red as the longer red and infrared wavelength light significantly interferes with vision through night vision goggles (NVGs). However, shorter wavelength red light can be employed to add a sufficient amount color to an NVIS compatible cockpit without greatly reducing visual performance through NVGs. Employing this concept, Honeywell's Aerospace Electronic Systems division developed a Color Multifunction Display (CMFD) to replace the existing monochrome cathode ray tube based multifunction display with which the Block 40 and newer F-16's are currently equipped. The CMFD is a 4-inch by 4-inch display that can provide the pilot with both symbology and video in different ambient conditions (e.g., full sunlight to low starlight levels) including an NVIS compatible lighting mode, for use with NVGs.

To determine if the new color multifunction display could be physically integrated into older aircraft flown by the Air National Guard and Air Force Reserves, the Air National Guard and Air Force Reserve Test Center (AATC/DO) in Tucson, AZ, asked for Honeywell to demonstrate their display on an NVIS compatible aircraft at AATC/DO. After preliminary testing in Tucson, some observers felt that the new CCIP CMFD (CCMFD) suffered from a few noteworthy problems. First, the image quality of the display when set in NVIS mode was not as good as pilots would prefer for many of the F-16's missions. In addition, pilots felt that the display was too dim to easily read small symbols and characters on the CCMFD under certain conditions after prolonged exposure to bright NVGs. Initially, this was attributed to possible loss of dark adaptation due to prolonged exposure to NVGs, some of which are capable of presenting a 5 fL image to the observer, under the proper conditions. Experimentation at the Air Force Research Laboratory, Human Effectiveness Directorate, AFRL/HECV, Wright-Patterson AFB showed bright adaptation to not be an influential factor.

As a result of these tests, the F-16 System Program Office (SPO) asked AFRL/HECV, Wright-Patterson AFB to examine the issues noted by AATC/DO and demonstrate the visual phenomena in the laboratory. At the end of January 2001, Honeywell provided two CCMFDs for examination at Wright-Patterson AFB.

MEASUREMENTS AND DATA

Factors influencing the visibility of a target include, but are not limited to: size, contrast, luminance, and duration. To examine the displays, a number of quantitative laboratory tests were used to examine the size and luminance of images displayed on the CCMFD. Target contrast was not explicitly examined since, at the luminance levels involved in this effort, visibility is a function of the image displayed (eye limited) than the display itself. Target duration was not examined either, as it is more closely related to the amount of time an observer has to study the display, or observer workload. In addition, display spectral radiance, NVIS radiance, and luminance uniformity were also measured. A low-fidelity cockpit

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **2001**	2. REPORT TYPE	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **The Visibility of Night Vision Imaging System Compatible Displays**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AFRL/HECV,2255 H St Rm 300,Wright Patterson AFB,OH,45433**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

simulation was also assembled to recreate a number of visual phenomena under controlled conditions that were reported from initial operational testing.

Spectral Measurements

A considerable amount of data could be obtained by measuring the spectral content of the light emitted from the display. Display radiance, NVIS radiance, luminance, and color coordinates can all be calculated once the spectral content of the emitted light is known. Measurements were made using a radiometer capable of measuring NVIS radiance. A four-segmented image made up of quadrants of color: red, green, blue, and white, was placed on the display (Figure 1 left). Measurements were made at three luminance levels: full NVIS bright, half full bright, and one increment above off. To get the fifth color, black, a second quadrant target was displayed and measured. The display NVIS A and B radiance, luminance and chromaticity data are displayed in Table 1.

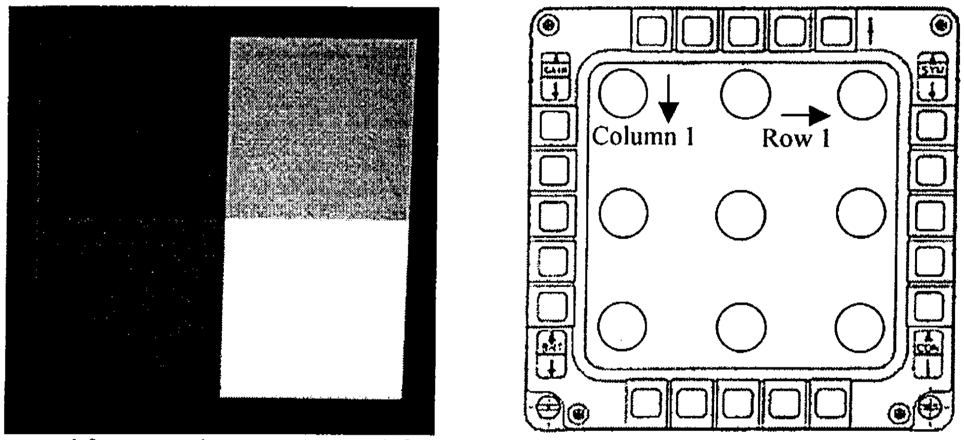

Figure 1. Target used for spectral measurements (left). Relative locations on the CCMFD of the luminance uniformity measurements (right).

Table 1. Display NVIS radiance, luminance, and UCS chromaticity for S/N 902002, display set to full bright.

	NVIS A	NVIS B	Luminance	u'	v'
Red	5.35E-08	3.48E-09	0.226	0.4028	0.5306
Green	4.47E-09	2.70E-10	0.559	0.1547	0.5497
Blue	1.83E-09	2.83E-10	0.118	0.1060	0.4111
White	1.66E-08	1.20E-09	0.878	0.1996	0.5258
Black	2.35E-08	1.33E-08	0.003	0.1846	0.5160

Character Size Measurement

The impact of the physical size of a target on its visibility is easy to understand. Larger targets are simply easier to see.[1] To measure the characters of interest, the individual files were first printed in the proper aspect ratio using a high quality laser printer (600 dpi). Symbols were then measured from the paper using a 20X loupe and reticule. To check these measurements, a number of characters were measured both off the paper printouts and directly from the displays themselves using the same loupe and compared. Comparison of the two sets of measurements showed both approaches to yield the same results to within the accuracy of the measurement loupe.

The smallest, dimmest characters (the characters most difficult to see) were the blue letters and numbers, measuring 2.25 mm high and 1.5 mm wide (Figure 2 left). Observing these symbols at 28 inches, the nominal observation distance for this display in the F-16, the characters would be 10.9 arc minutes tall. This converts to a Snellen acuity of about 20/44. One should note that the displayed characters were not similar to those commonly used in acuity testing, and did not exhibit the defined length to width to stroke aspect ratio. The actual visual acuity of these characters was undoubtedly worse. The symbol sets used were not the symbology commonly used on the F-16 MFD, but rather were the result of the manufacturer's best guess at what the aircraft symbol generator might present on the display.

Luminance Uniformity

In addition to the spectral measurements described in the previous section, the luminance uniformity can also impact the visibility of parts of the display. The test required the display to be illuminated all in one color. The display's

luminance was measured for nine locations (Figure 1 right) using a Minolta hand-held photometer. Display uniformity was measured for red, green, blue, and white. The most noticeable trend found in luminance uniformity was a decrease in display luminance as the measurements moved farther from the top edge of the display. The percent uniformity (*Uniformity*) was calculated for each tested color using the following equation:

$$Uniformity = \frac{Max - Min}{Max} \times 100\%$$

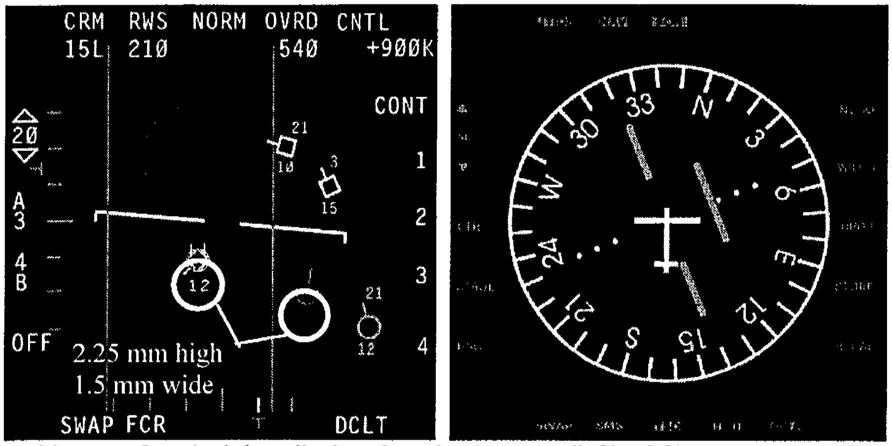

Figure 2. Conceptual image of tactical data displayed on the CCMFD (left). CCMFD compass demonstration (right).

Here, *Max* and *Min* are the maximum and minimum luminance respectively, measured for a particular color from the display. The resulting calculated percentages are listed in Table 2.

Table 2. Luminance uniformity of the CCMFD (S/N 902002) for the four measured colors expressed as a percentage.

Color	% Uniformity
Red	7.7
Green	12.9
Blue	13.3
White	13.3

Vision Demonstration

To better examine the interaction between the display, the cockpit, and the night vision goggle, a demonstration was assembled in a laboratory at AFRL/HECV. This demonstration placed observers in a simulated cockpit with the CCMFDs and required them to assess their own visual performance under a number of conditions. Observer comments were noted and reviewed to determine the combinations of conditions under which visual performance was unacceptably degraded.

Conditions and Procedure

To assemble the cockpit simulation, the displays were placed in the correct geometry with respect to the observer's eye position using information provided by Lockheed-Martin. An electro-luminescent (EL) panel was mounted to a post near the displays to add additional NVIS "compatible" light, simulating the effect of other lights in the cockpit. The light from the EL panel was diffused by reflecting it off a large, flat, white surface. A 3X3 NVG resolution target (Figure 3 left) was placed in space 15 feet from the observer position. The target was provided as a visual performance reference to assist the observers in assessing the impact of the different display and lighting conditions. A sheet of Plexiglas was placed between the observer and the acuity target to reflect EL light back towards the observer. This created a veiling luminance that could interfere with visual performance under the proper conditions (Figure 3 right) as a windscreen would in a real cockpit.

The experimental conditions examined were based on the observations made at AATC/DO. It was expected that exterior target luminance and CCMFD luminance would have the largest impact on visual performance. In addition, the amount of additional cockpit lighting was also expected to affect vision, making it a logical factor to include. Finally, the level of NVG performance was also suspected, not necessarily of being a factor affecting vision by itself, but of being part of an interaction involving the display luminance and cockpit lighting. Goggle performance was therefore included as a factor. One should note that newer NVGs tend to have improvements in a number of parameters, including higher gain, higher spectral sensitivity, and different minus-blue filters, making them perform differently than older goggles. Due to the

limited number of NVGs available for this demonstration, it was impossible to differentiate the effects of the different NVG parameters on vision.

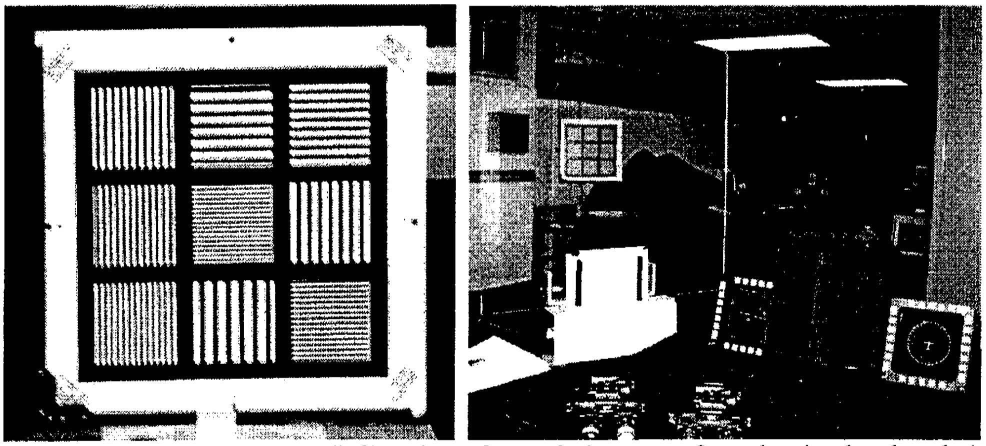

Figure 3. 3X3 NVG resolution target (left). View of a resolution target from the simulated cockpit (right).

Two levels of each factor examined were used in the demonstration. The target luminances presented to the observers were half moon ($1.18X10^{-2}$ fL) and half starlight ($2.94X10^{-4}$ fL). The bright and dim conditions for the CCMFD were established by the amount of the display illuminated. For the dim conditions, images having bright characters on a black background (Figure 2), were displayed. The bright condition employed images where the whole display was illuminated to some degree, such as forward-looking infrared (FLIR) imagery and a full-color moving map (Figure 4). One should note that these images were intended for marketing demonstrations only and do not accurately reflect information normally displayed on the F-16 multi-function display. Two levels of additional extraneous NVIS "compatible" lighting were also examined in the demonstration. The two levels used were 1 fL to represent the luminance level commonly found in bright NVIS compatible cockpits ("on"), and no additional light ("off"). As noted earlier, the two NVGs examined were both AN/AVS-9's. Observers were presented all combinations of these four factors, creating 16 experimental conditions.

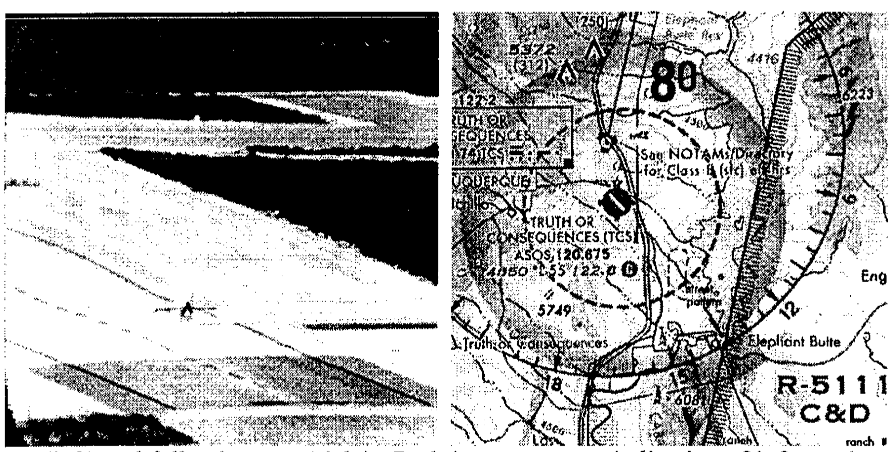

Figure 4. FLIR image (left) and full color map (right). Both images are not indicative of information currently displayed on the F-16 MFD.

At the start of a demonstration session, observers were allowed to dark-adapt for 10 to 15 minutes. During this time, instructions regarding the task were given. Observers were also told that the goggles were pre-focused and that they were not to adjust them. The observer would first look through the C model NVG at the acuity target and call off the number of gratings that they could resolve. Then the observer was asked to continue looking through the goggles at the acuity target for approximately 5 minutes. This 5-minute adaptation was intended to readjust the observer to the bright goggle output and was only performed once at the beginning of the session. The observer was then instructed to look at the display and report what they could or could not see.

The experimenter running the demonstration asked several questions. For the dim CCMFD conditions, observers were asked if they could see all of the colors on the display. They were asked if they could see all of the displayed symbols and

the accompanying numbers. Observers were asked about the appearance of the colors. They were asked if the colors looked like they should, such as, could they readily interpret red as red, blue as blue, and so forth. In addition, observers who were also pilots were asked if they could see the display well enough to accomplish a mission. The observer then looked through the G model NVG at the acuity target and noted the number of gratings they could resolve. They then continued to look through the goggles at the acuity grating for approximately 1 minute and then looked back at the display and the questions repeated. These procedures were repeated for all the conditions alternating between the C and G model NVGs.

Discussion

Observers largely felt that the symbols and imagery presented by the displays were visible. The colors displayed with greater luminance, such as white, green and yellow, were considered easily visible. Red and blue were more difficult to see but were still considered visible to a large percentage of the observers. The majority of the observers also considered FLIR imagery displayed on the CCMFD visible. However, pilots felt they needed more detail to accomplish a ground attack mission.

Significant additional detail could be obtained from the FLIR video by simply increasing the display luminance, indicating that the visibility of the video was limited by the observer's eye during the demonstration, not the CCMFD. This was demonstrated in the laboratory when one pilot was allowed to adjust the display luminance and contrast to what he considered optimal using the display's daylight mode. Considerable additional detail became visible including ground crew near parked aircraft and aircraft features such as the refueling probe on an A-6 Intruder. The display luminance of this "optimal" setting was measured to be approximately 90 fL using a handheld photometer. Unfortunately, using a display capable of that brightness at night is impractical for many reasons, such as increased cockpit reflections and veiling luminance. The probability of any manufacturer building a 90 fL display that is NVS compatible in the near future with existing technology is low.

One observer stated it most clearly by saying, "I didn't see a problem here... ...but I would be hesitant to say the plane does not have a problem." The demonstration employed a subjective, simple task that did not duplicate the conditions under which the display is normally employed. To improve the demonstration and better quantify the display would have required more time and resources than were available at the time of the CCMFD evaluation. As noted earlier, observers were not all pilots. Most observers did not have a clear idea about how NVGs and NVIS lighting interact with the human visual system. Observers were also allowed to assess their own visual performance since time did not allow for a more objective assessment. In addition, observers were allowed to look at the display longer than what a pilot would, improving their visual performance since target duration often affects target visibility.[2]

There were a number of concerns raised by the pilots who saw the cockpit simulation. The first issue was with the additional NVIS cockpit lighting. Pilots felt that the lighting present in the simulation was not bright enough and there were too few light sources placed around the cockpit. In addition, it was determined through questioning that pilots fly with their cockpits brighter than simulated in the demonstration. A number of small but critical displays, the Horizontal Situation Indicator and fuel totalizer in particular, must be bright enough for the pilot to read in flight. In order to increase the luminance of those displays, pilots are forced to increase the luminance of all of their cockpit instruments since the luminance of a particular instrument cannot be adjusted independently of the others in the cockpit.

Non-pilot observers tended to have their attention drawn to large, easy to see objects in the FLIR video, such as the airplane on the runway (Figure 4). Targets of interest to a pilot attacking a ground target will be relatively small and probably camouflaged. There were a number of small, low contrast details in the video. But only one observer noticed any of these. Therefore, it is difficult to conclude that the relevant details would always be visible when displayed at the luminance levels examined. Observers could not comment on the visibility of targets they simply could not see if they did not know they were there. There was no easy alternative by which more realistic targets could be embedded in the marketing demonstration video, making this aspect of the demonstration more realistic.

Visibility Requirements

In order to meet the radiance limits set in the military NVIS lighting specifications, MIL-L-85762A and its current revision MIL-STD-3009, display luminance can become somewhat limited. The added complexity of balancing the three primary colors to create an acceptable white forces extra restrictions on the display manufacturer. These two factors combine to limit the output luminance of color NVIS displays. Historically, NVIS display maximum luminance was limited to about one or two footLamberts to avoid the potential for the NVG wearer to encounter bright adaptation to their 1.6 fL goggle output, which was thought to make reading and interpreting cockpit instruments difficult. Current research shows that NVG bright adaptation does not interfere with the legibility of cockpit instruments until goggle-to-cockpit luminance ratios of 100 to 1 or more are reached. In addition, pilots tend to fly with their instruments set to maximum

luminance output in order to make certain all of their displays are visible, minimizing the luminance ratio. The information displayed should be tailored for good visibility under low luminance conditions.

Table 3. Minimum requirements for target visibility at the 50% probability of seeing. These results are an extrapolation of Cob and Moss's data. N/V – target not visible

	Acuity (MOA)			% Contrast		
Target Luminance	At 50% Contrast	At 10% Contrast	At 5% Contrast	For a 4 MOA Target	For a 2.4 MOA Target	For a 1.35 MOA Target
1.0 fL	1.5	3.3	5.8	7	16	59
0.1 fL	2.1	4.9	8.9	13	27	N/V
0.01 fL	3.0	7.4	13.6	22	47	N/V

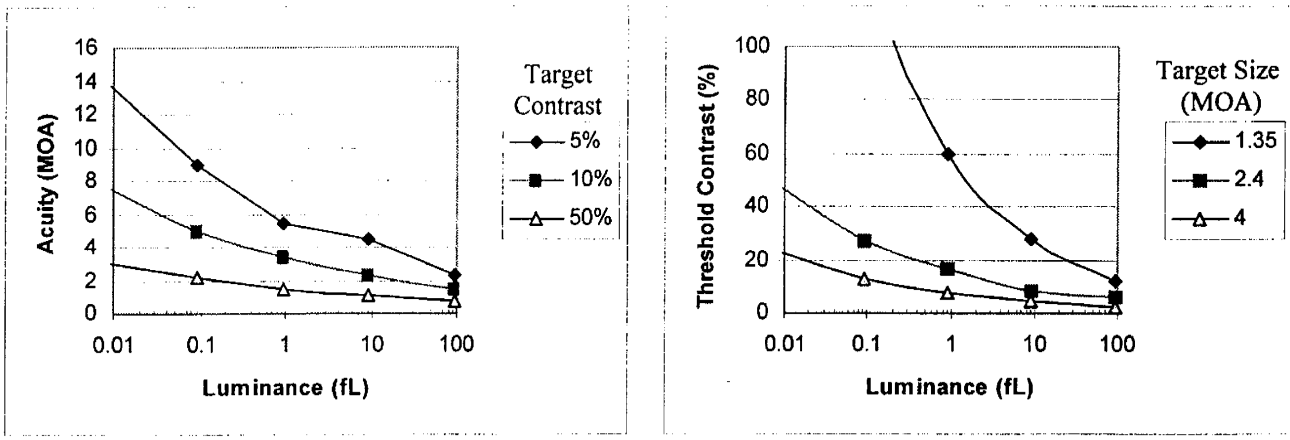

Figure 5. Acuity as a function of target luminance (left). Threshold contrast as a function of target luminance (right).

Cob and Moss did much work examining the effect of target luminance on visual performance.[1] An extrapolation of their results to target luminances lower than they examined appears in Figure 5 and Table 3. This extrapolation was made possible because of work done by Connor and Ganoung. Their work indicated that the trends in visual performance documented by Cob and Moss were still valid at luminance levels up to two orders of magnitude lower than those studied by Cob and Moss.[3] Figure 5 and Table 3 show that large objects of relatively high contrast should be visible in the FLIR imagery. However, they also show that the contrast needed to see smaller, dimmer tactically interesting (and probably camouflaged) targets is considerable. These targets would simply not be visible to an observer, not because the display cannot portray them with the appropriate fidelity, but because the targets themselves do not have the necessary contrast with their background to be seen when displayed at low luminance. Under these conditions, the human eye limits visual performance.

The extrapolation of Cob and Moss's data also shows that the characters used in the CCMFD tactical display should be visible (2.4 MOA on the display > 2.1 MOA required at 0.1 fL). However, two factors must be addressed before drawing a conclusion: Cob and Moss's threshold criteria and target duration. Cob and Moss's data and, thus, their visual models are based on the 50% probability of seeing. However, for relaying information to a busy pilot, a 50% probability of receiving the information they need is probably insufficient. Pilots would probably prefer a 100% probably of seeing. In addition, pilots do not have much time to dwell on their displays. Cob and Moss's research indicated that the length of time the target is visible impacts its visibility. This would further complicate extraction of information from a display for a pilot that would not manifest itself in a static assessment of visual performance.

CONCLUSIONS AND COMMENTS

The data gathered in this effort showed that the Honeywell CCMFD passed MIL-L-85762A NVIS B specification, as required. The color balance between red, green, and blue allowed the display to achieve the full color sought for applications like moving maps. Also, the color coordinates selected by Honeywell for red, green, and blue were well chosen, allowing for easy color discrimination and identification. In general the Honeywell CCMFD is not NVIS A compatible as it was capable of emitting a significant amount of red light. However, this was not a program requirement.

The visibility of the display was found to be acceptable but marginal. An examination of the acuity and contrast requirements for low luminance targets yielded some evidence as to why. Character sizes exceeded threshold requirements

as defined by the 50% probability of seeing. However, a 50% probability of seeing may be insufficient for the acknowledgement of information from an aircraft cockpit display. The amount of time a pilot has to read their displays influences the display visibility, further compounding the problem. Display visibility could be improved by increasing the luminance in the NVIS mode. However, increasing the luminance could negatively impact NVIS compatibility. Characters on displays like the compass and the tactical display (bright characters on a dark background) could be made larger to improve visibility. Unfortunately, it is unlikely that the display itself could be made larger since the F-16 MFD is currently limited in size due to cockpit constraints.

In the future, a more controlled experiment should be conducted to accurately quantify visual performance under the luminances produced by the Honeywell CCMFD and study the interaction between the display and NVGs. This research should examine more realistic conditions. Additional and brighter cockpit lighting should be included to more accurately simulate the NVIS cockpit. Observers should be given a primary task that occupies most of their attention and be restricted to quick glances at the display symbology. Finally, a real F-16 canopy should be included in the simulated cockpit to induce the proper reflection intensities and geometries, which may play a larger role than initially suspected.

ACKNOWLEDGEMENTS

The author would like to express gratitude to the organizations and people who, through much coordinated effort, brought this research to fruition. First, the author would like to thank LTC Steve Coubrough and Maj. Jim Henderson of AATC/DO for their initial work describing and documenting their concerns about the CCMFD and their personal assistance and the loan of equipment instrumental to the display's analysis. In addition, thanks are extended to Catherine Griffin, Ted Wood, and Brian DeBruine of Honeywell for supplying the displays and the technical support needed to run them. Also, the author would like to thank Robert Colby and Laura Durnell of Lockheed-Martin, for supplying the necessary information on the F-16 cockpit for the proper assembly of the simulated cockpit. Thanks are extended to Rick Bowyer and Bud Boulter (ASC/YP) for providing much of the coordination between organizations and many of the pilots and observers used in the assessment. Finally, special thanks are extended to Fred Meyer (AFRL/HECV), Maryann Barbato, David Sivert, Sharon Dixon, Martha Hausman (Sytronics, Inc.), Terry Trissel, and Robert Schwartz, (Logicon Technical Services Inc.), for their invaluable assistance in the setup and execution of the laboratory bench testing and the visual demonstration.

REFERENCES

[1] Cobb, P.W., Moss, F.K., *The four variables of the visual threshold*, Journal of the Franklin Institute, Vol. 205, Issue 831, 1928.

[2] Cobb, P.W., Moss, F.K., *Four fundamental factors in vision*, Transactions of the Illuminating Engineering Society, Vol. 22, No. 5, 1928.

[3] Connor, J.P., Ganoung, R.E., *An experimental determination of the visual thresholds at low values of illumination*, Journal of the Optical Society of America, Vol. 25, No. 9, pp. 287-294, 1935.

BIOGRAPHY

Peter L. Marasco joined the U.S. Air Force community in 1991 as a civilian research physicist. His work as an optical engineer has concentrated primarily in the areas of Aerospace Transparency Technology and Night Vision, conducting basic research, guiding and executing optical and opto-mechanical design efforts, evaluating concepts and prototypes, and developing and improving optical test methods. Dr. Marasco received a BS degree from the University of Rochester in 1991 and an MS degree from the University of Arizona in 1993, both in Optical Engineering. In 2000, he received his Ph.D. from the University of Dayton in Electro-Optical Engineering. Dr. Marasco is currently examining and modeling visual interference mechanisms common in modern aircraft cockpits.